Direct influence of solar spectral irradiance on the high-latitude surface climate

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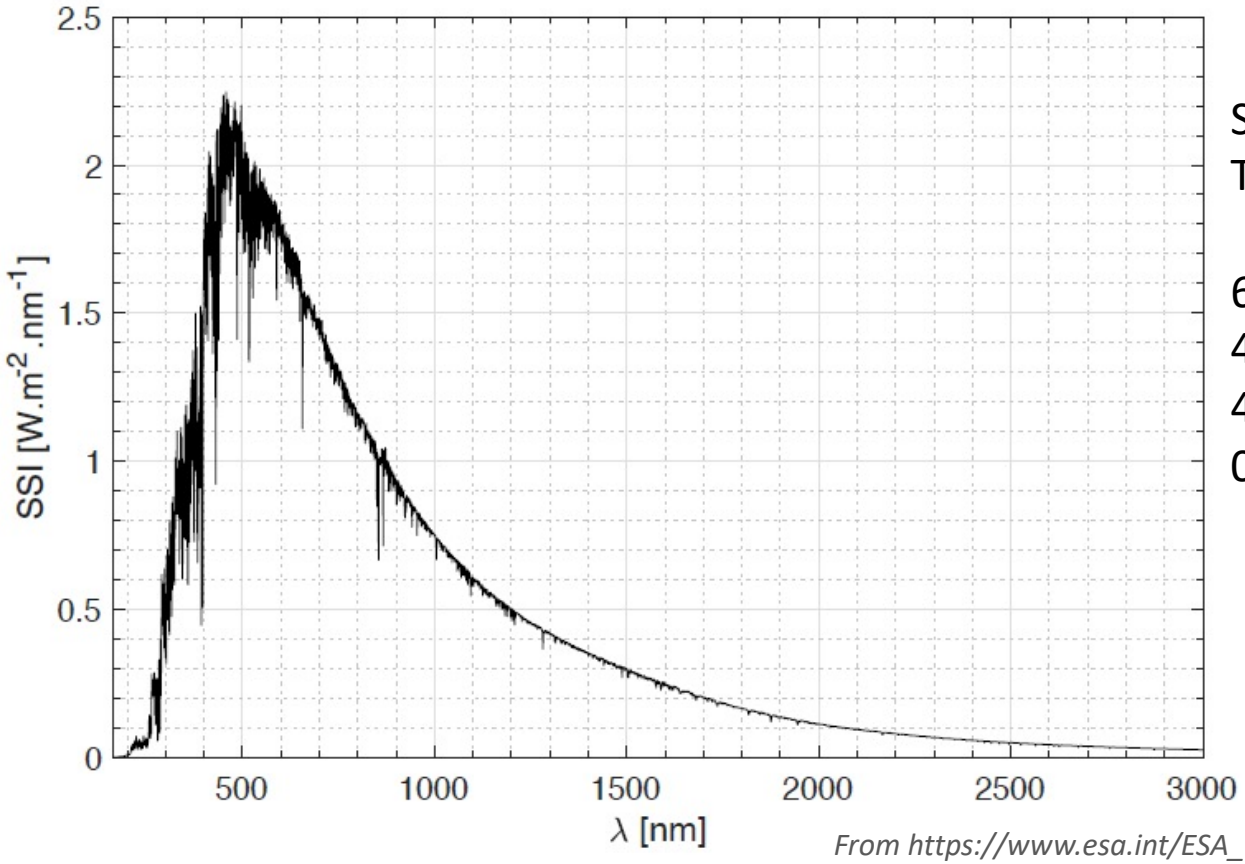


SSI: solar spectral irradiance
TSI: total solar irradiance

6.4% from UV (0.1-0.38 μm)
48.1% from Visible (0.38-0.78 μm)
45.0% from Near-IR (0.78-5μm)
0.6% from IR >5μm

From https://www.esa.int/ESA_Multimedia/Images/2017/12/Solar_spectrum

Question to be addressed:

Assuming that two sets of SSIs have identical TSI but different partitions between visible and near-IR SSI, then, when they are used in the climate model simulations separately, will the simulated climate be the same or statistically different?

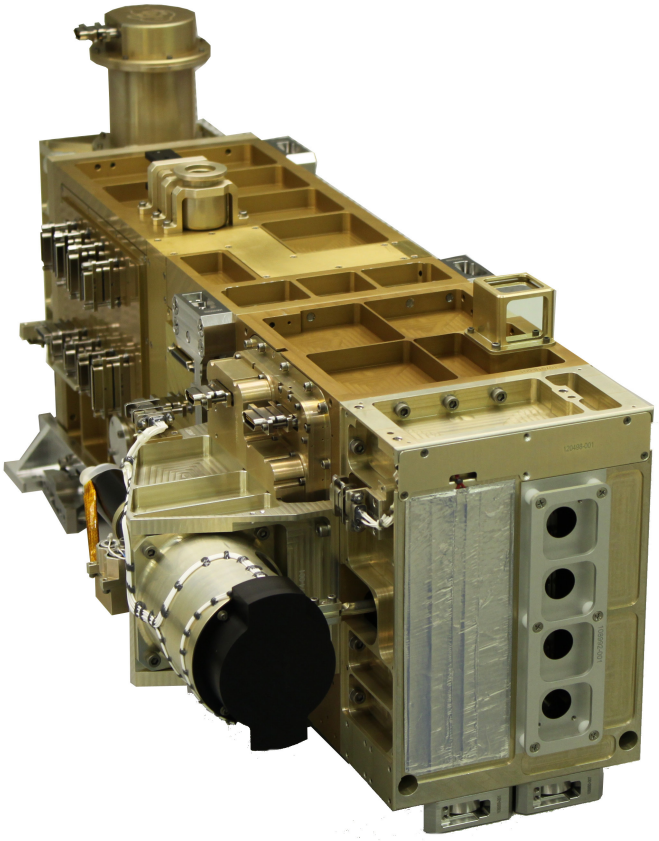
Different partitions: CMIP6 default vs. TSIS-1 observations

Starting Points

- Sun-climate connection matters
- Both TSI and SSI matters: the
  - TSI: “bottom-up” mechanism
  - SSI: “top-down” mechanism for UV SSI
    - UV→ozone →strato. radiative heating →temperature gradient → strato. circulation →STE →tropo circulation →surface climate
    - Little discussion about VIS and near-IR
      - Partly limited by the past observations
- CMIP6 solar forcing data set (1850-2300; Matthes et al, GMD, 2017)
  - Used by all modeling centers

TSIS-1 SSI measurements

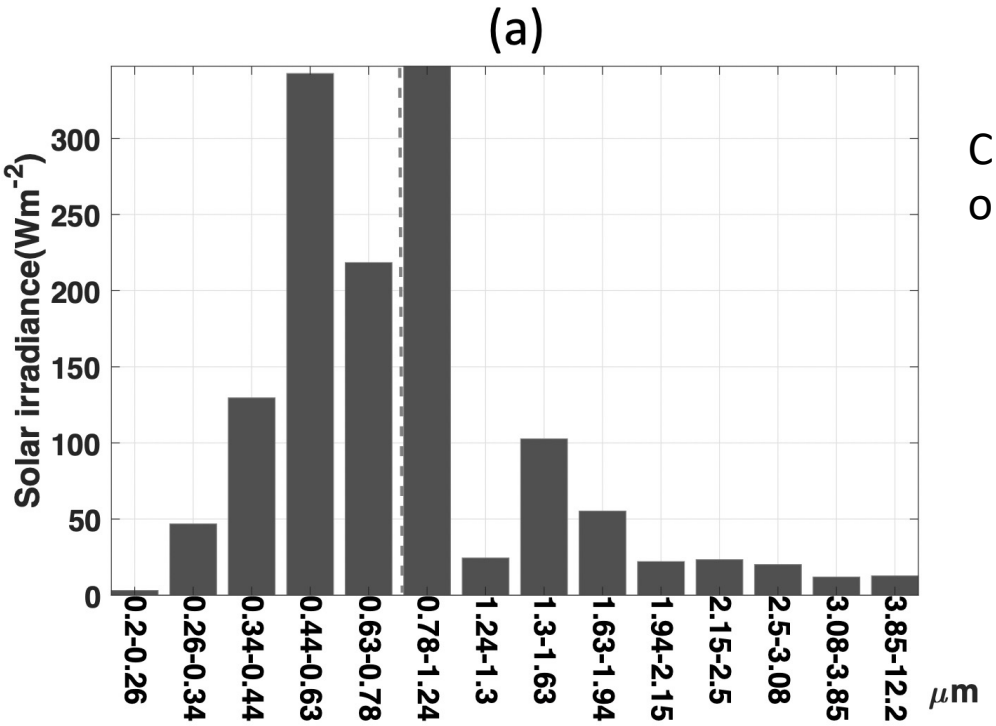
- Successor of SORCE SIM
  - TSIS-1 SSI covers 0.2 to 2.4 μm
- Improved performance for visible and near-IR SSI
  - 0.25% radiometric uncertainty (10x better than before)



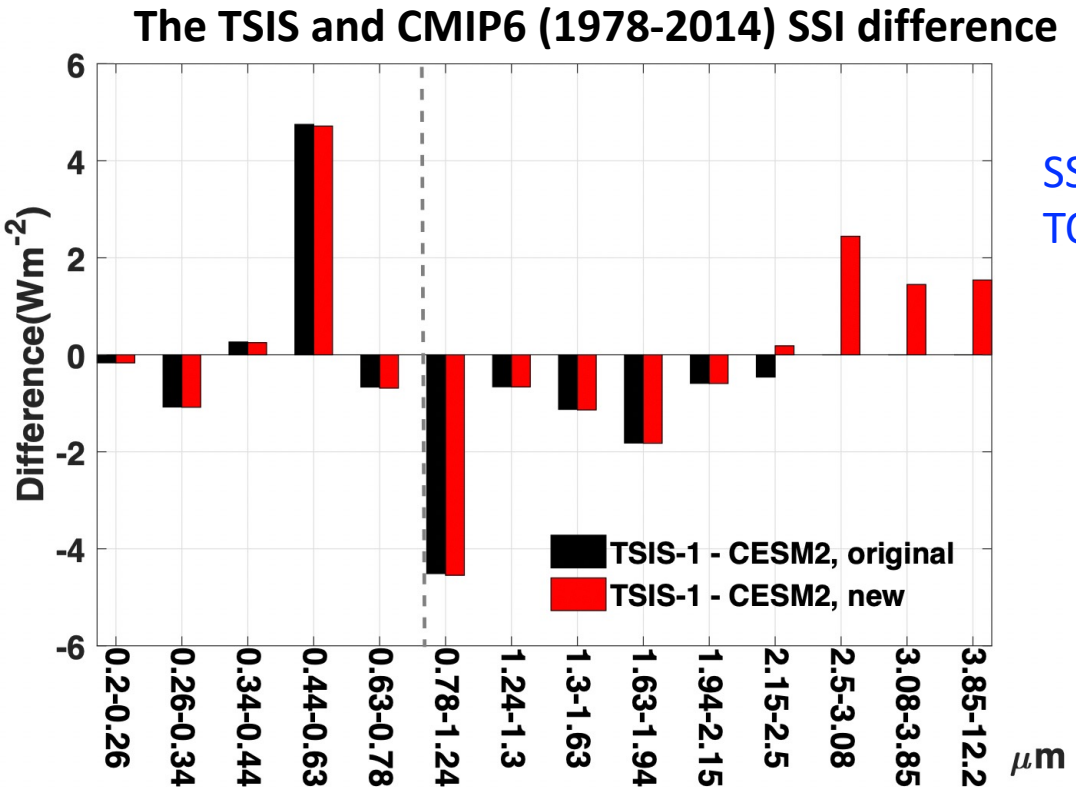
TSIS-1 SIM
(from lasp.colorado.edu)

CMIP6 Solar forcing dataset

	Mean (Wm^{-2})	Daily standard deviation (Wm^{-2})
TSI	1360.9	0.42 (0.031%)
UV	85.8	0.13 (0.15%)
Visbile	655.2	0.22 (0.034%)
Near-IR	613.6	0.10 (0.017%）



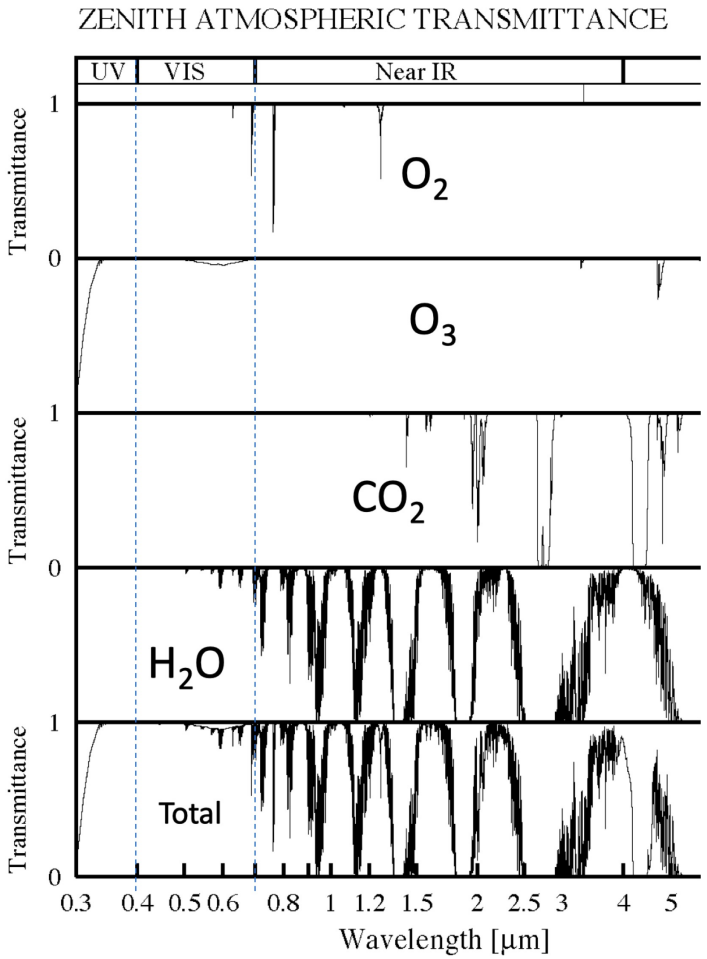
CMIP6 SSI: 1978-2014
on RRTMG_SW bands



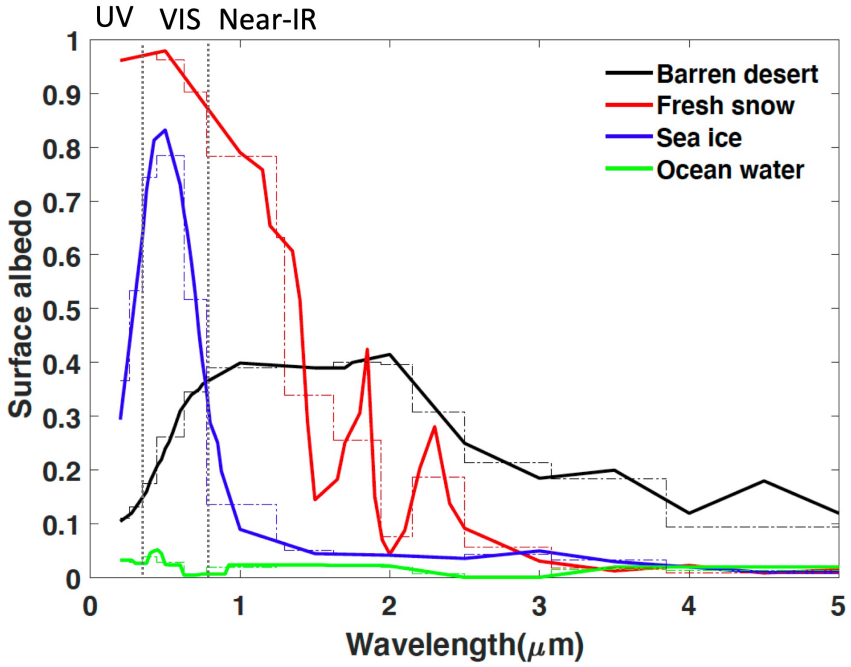
SSI is not TOA forcing
TOA forcing = SSI/4

- The difference is orders of magnitude lager than the temporal variations of SSI in CMIP6
- First-order question: how such differences between visible and near-IR can affect the simulated climate?
- Making two SSI datasets:
  - CESM2 SSI: 1978-2014 CMIP6 SSI scaled to TSIS-1 TSI by a factor of 1.00003
  - TSIS-1 SSI:
    - Within 0.2-2.4um, time-averaged TSIS-1 observed SSI
    - Outside, CMIP6 SSI but scaled to make the identical TSI as TSIS-1 observation

Why does VIS-NIR partition matter?



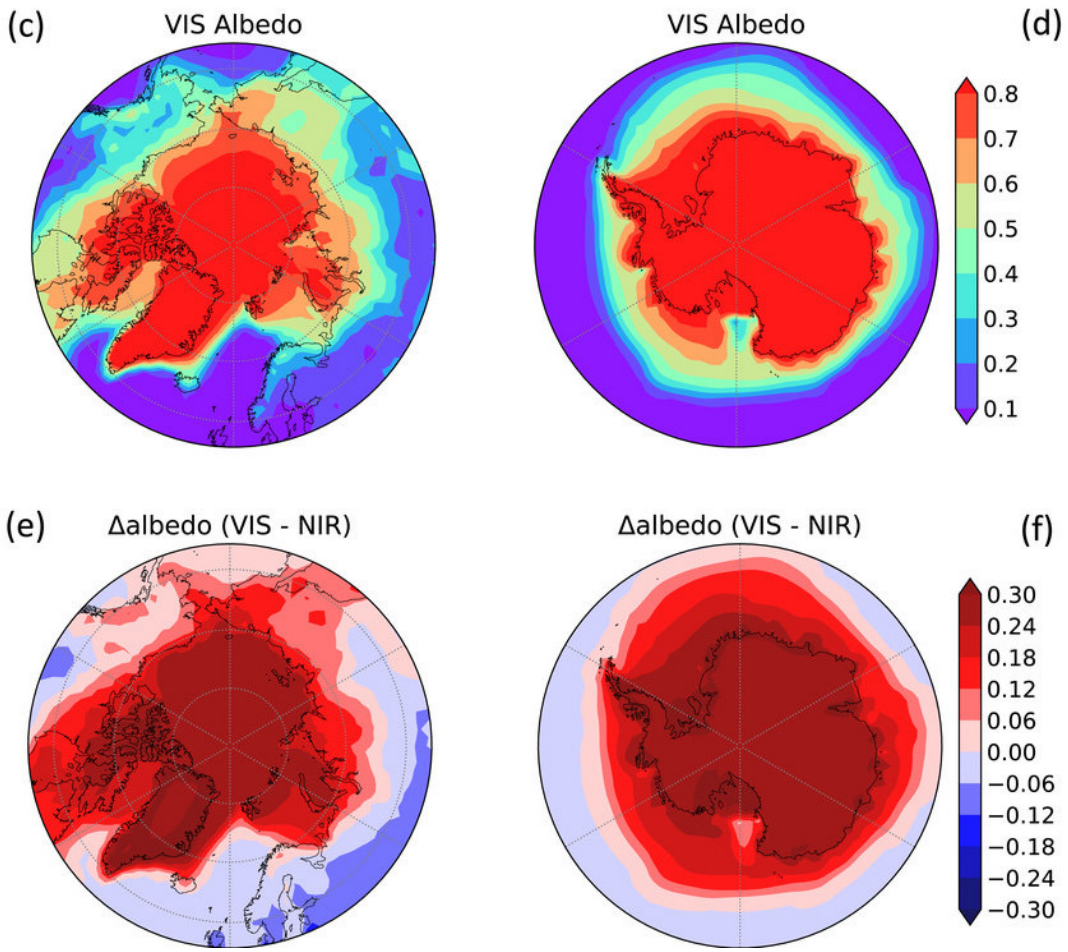
(Petty, Fig 7.6)



Sea ice vs. open water: VERY different reflections for VIS vs. NIR

H_2O: much more absorption in the near-IR than in the visible

CESM2 annual-mean surface albedo



CESM-2 numerical experiments

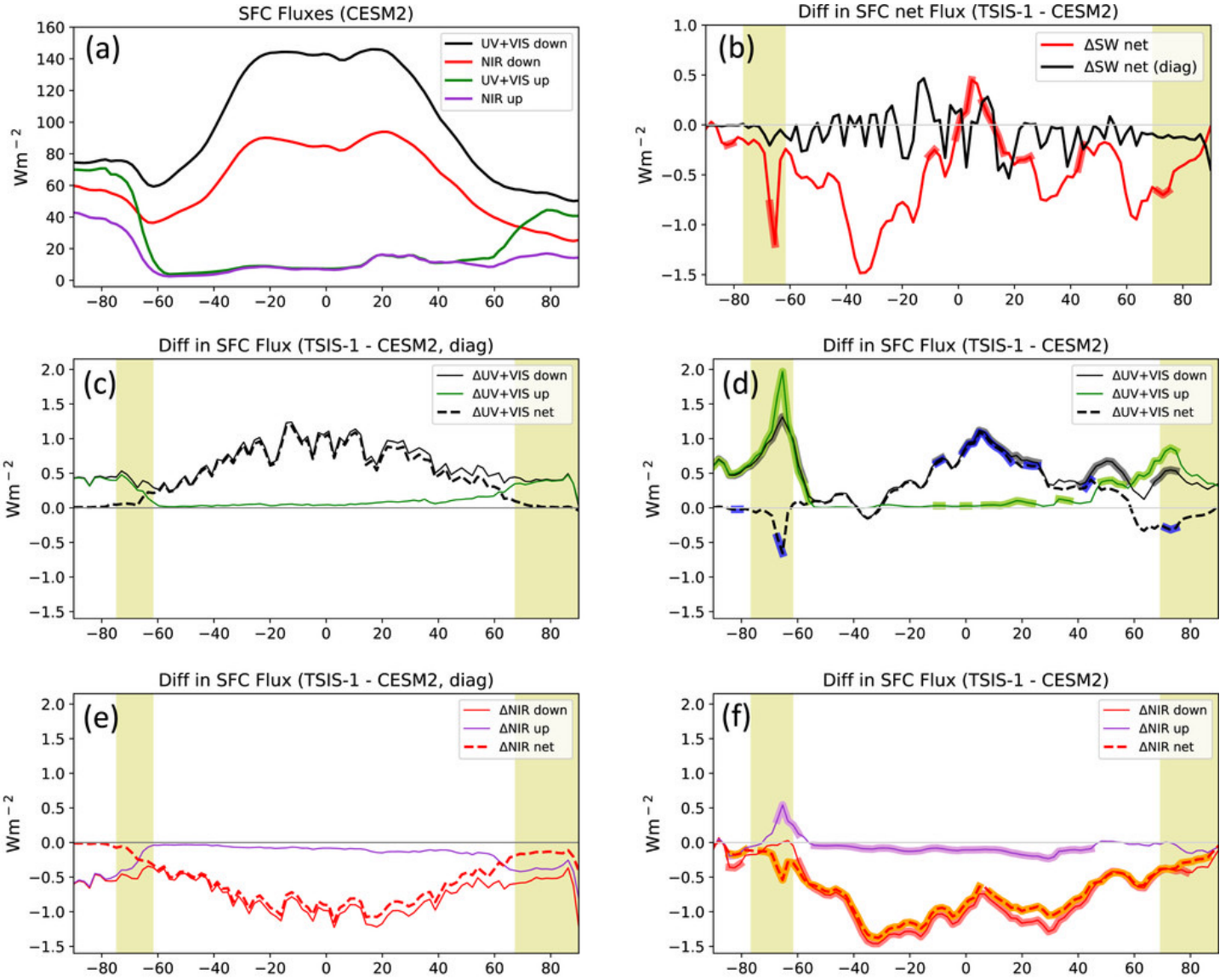
- Slab-ocean run at present-day conditions
- Four-member ensemble runs
  - One ensemble with CESM2 SSI (control)
  - The other with TSIS-1 SSI (perturbation)

    Identical TSI/Different VIS-NIR SSI

    TSIS-1 SSI has more in VIS and less in NIR than the CESM2 SSI
- 20-year simulations and last 10 years used for analysis
- 5-day diagnostic runs for 12 months: direct atmospheric response before radiative feedbacks kick in

Surface SW Flux (net positive downward)

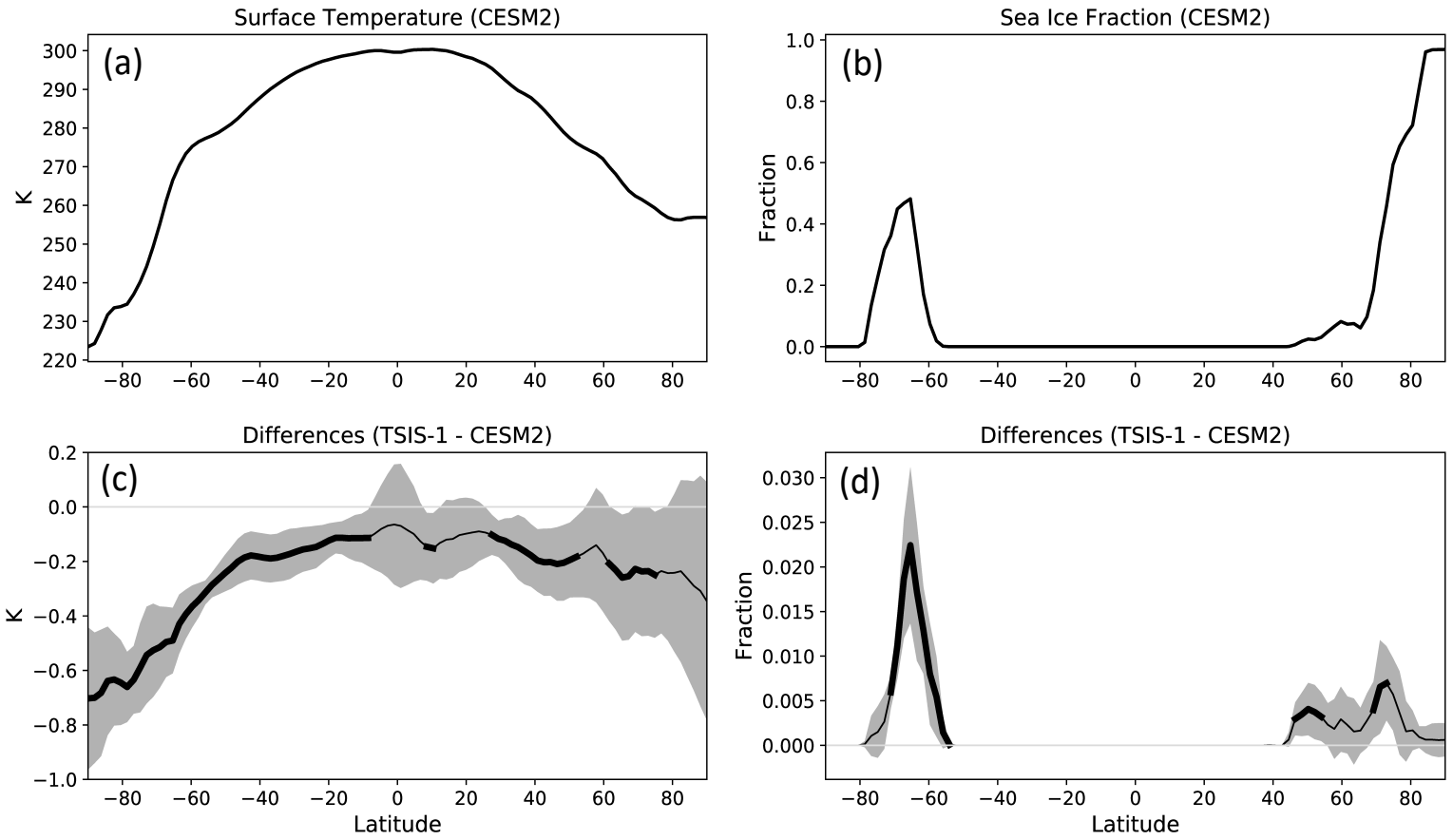
TSIS-1 has more SSI in visible than CESM2

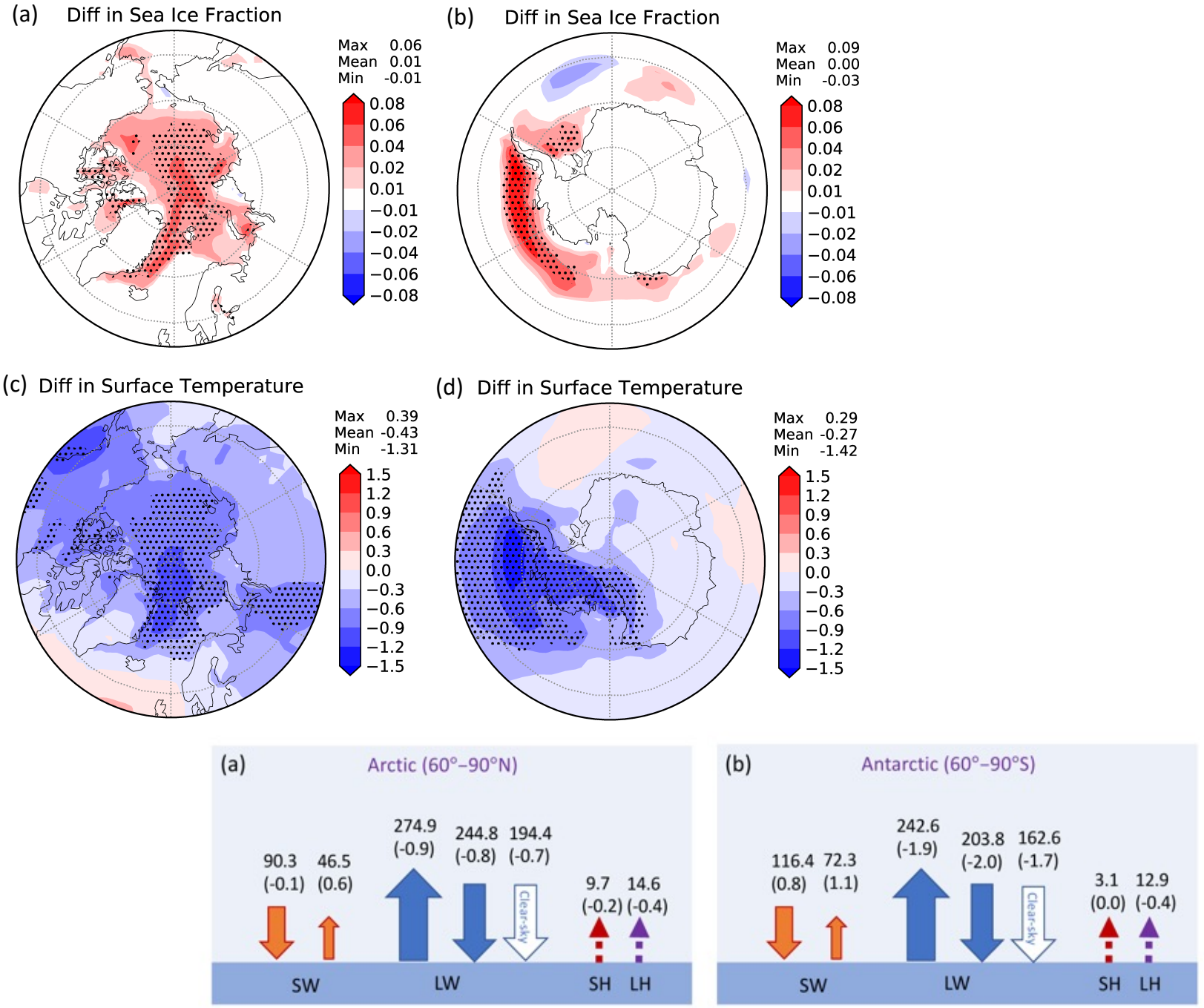


- Ensemble run: sea ice must play a role

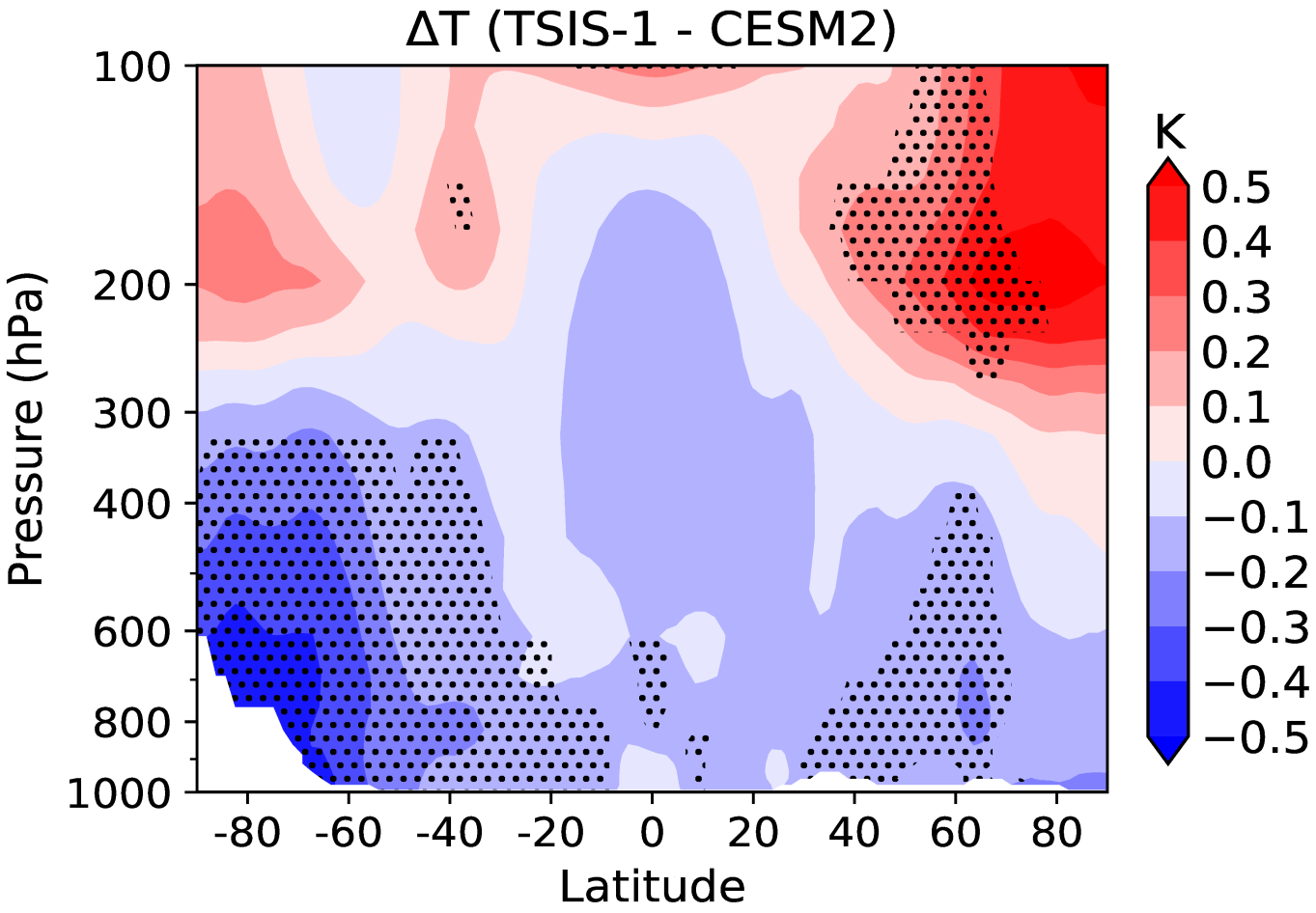
Vertical shades: sea ice changes are statistically significant

Zonal-mean climatology difference

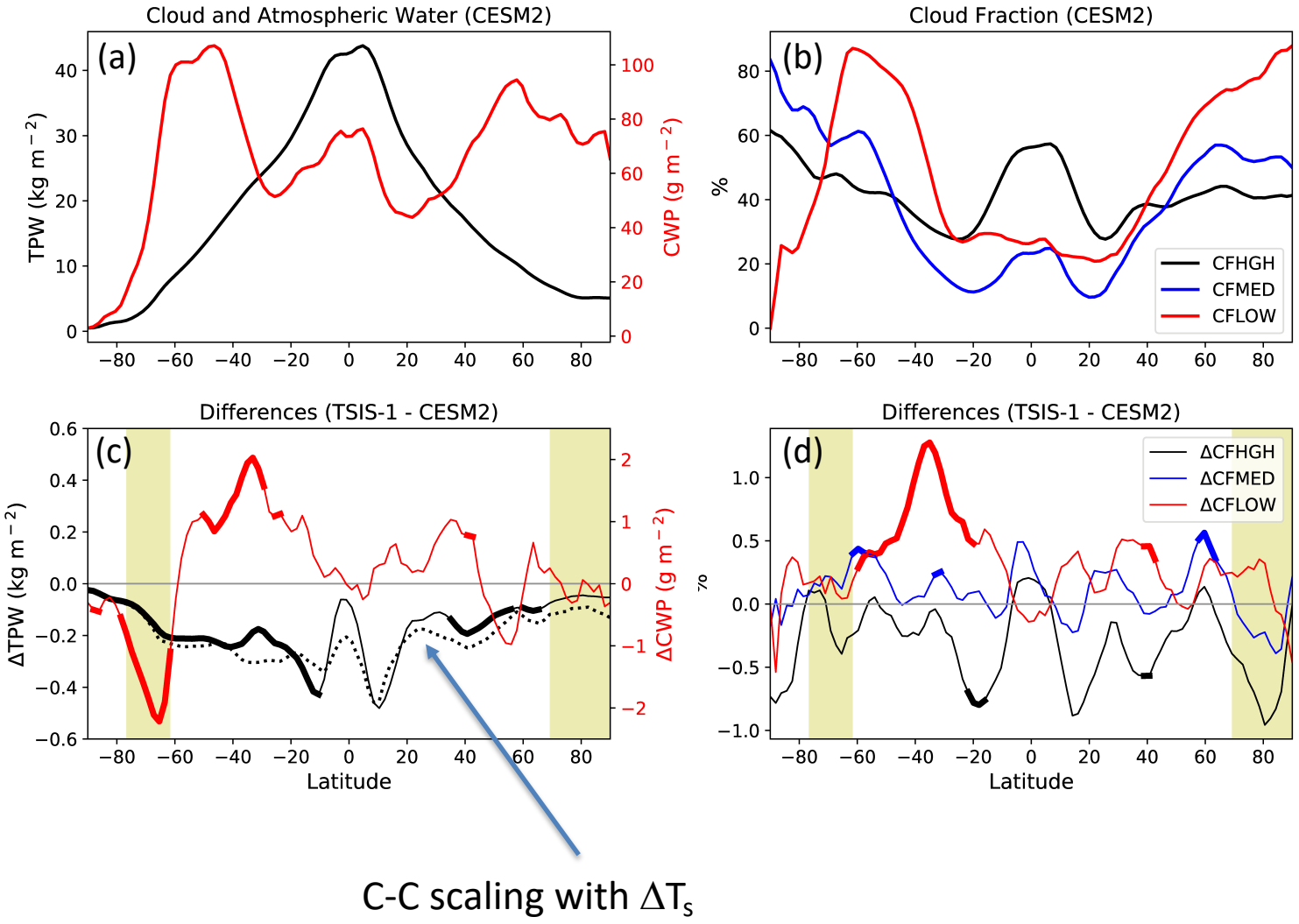



(a) Diff in Sea Ice Fraction
Max 0.06
Mean 0.01
Min -0.01
0.08
0.06
0.04
0.02
0.01
−0.01
−0.02
−0.04
−0.06
−0.08
(b) Diff in Sea Ice Fraction
Max 0.09
Mean 0.00
Min -0.03
0.08
0.06
0.04
0.02
0.01
−0.01
−0.02
−0.04
−0.06
−0.08
(c) Diff in Surface Temperature
Max 0.39
Mean -0.43
Min -1.31
1.5
1.2
0.9
0.6
0.3
0.0
−0.3
−0.6
−0.9
−1.2
−1.5
(d) Diff in Surface Temperature
Max 0.29
Mean -0.27
Min -1.42
1.5
1.2
0.9
0.6
0.3
0.0
−0.3
−0.6
−0.9
−1.2
−1.5
(a) Arctic (60°–90°N)
90.3 (-0.1)
46.5 (0.6)
274.9 (-0.9)
244.8 (-0.8)
194.4 (-0.7)
Clear-sky
9.7 (-0.2)
14.6 (-0.4)
SW
LW
SH
LH
(b) Antarctic (60°–90°S)
116.4 (0.8)
72.3 (1.1)
242.6 (-1.9)
203.8 (-2.0)
162.6 (-1.7)
Clear-sky
3.1 (0.0)
12.9 (-0.4)
SW
LW
SH
LH

Atmosphere temperature differences



TPW, CWP, and cloud fraction changes

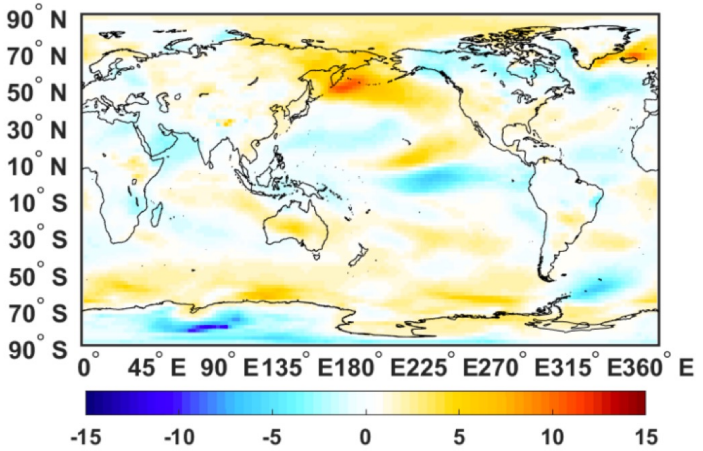


C-C scaling with ΔT_s

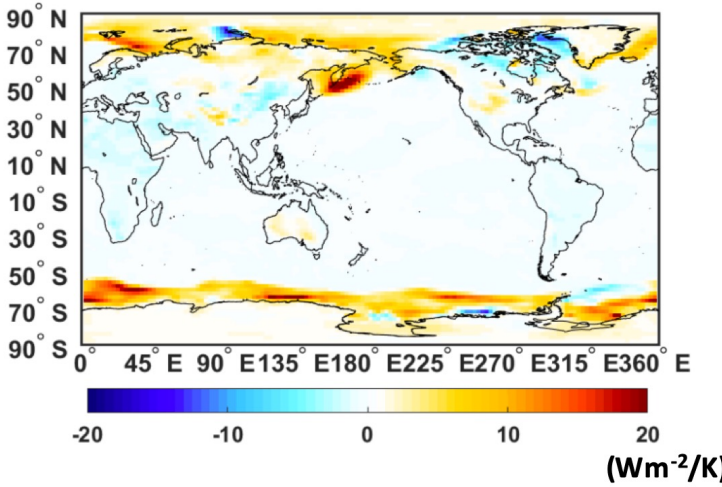
Feedback analysis (TSIS-1 – CESM2)

All-sky Feedback (Wm^{-2}/K)	
Planck	-3.01
Lapse-rate	0.49
water vapor LW	0.87
water vapor SW	0.28
Surface albedo	0.42
Cloud LW	-0.61
Cloud SW	0.70

Lapse-rate feedback



Surface albedo feedback



Conclusions

- A discrepancies between CMIP6 and TSIS-1 SSI in the visible and near-IR: as large as 4 Wm^{-2} in a given RRTMG-SW band with opposite signs between VIS and NIR
  - $\pm 1 Wm^{-2}$ TOA forcing.
- Even with the identical TSI, SSI partition between the visible and near-IR matters for the climate simulation
  - Disparity between visible and near-IR absorption by high-latitude surface (and atmosphere too)
- Spectral TOA forcing matters, not just the broadband TOA forcing
  - Ice spectral albedo feedback
- The merit of split SW: visible and near-IR reflected flux

THANK YOU!

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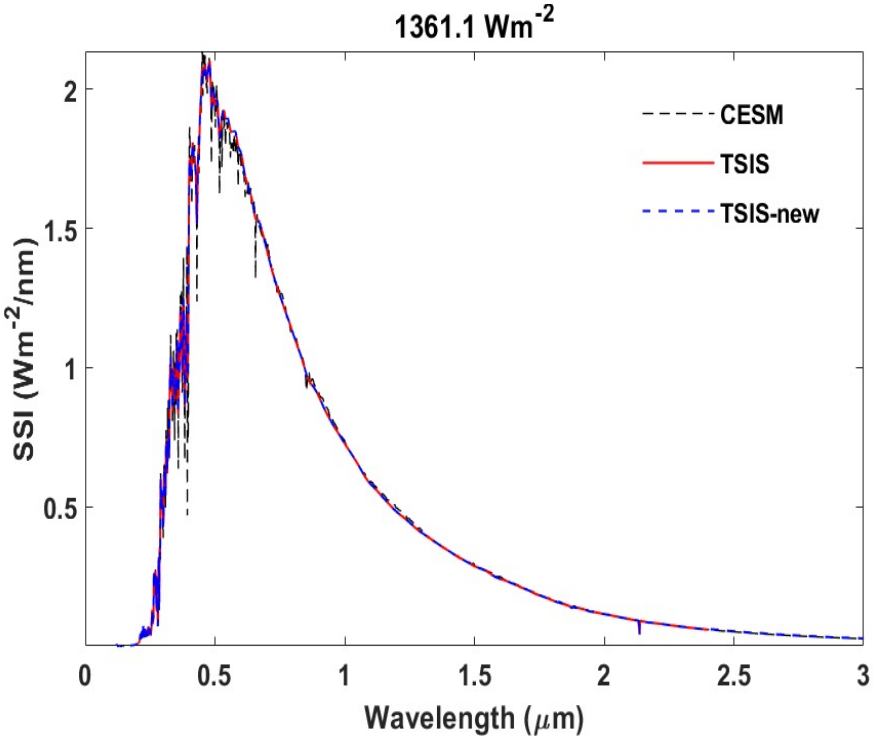

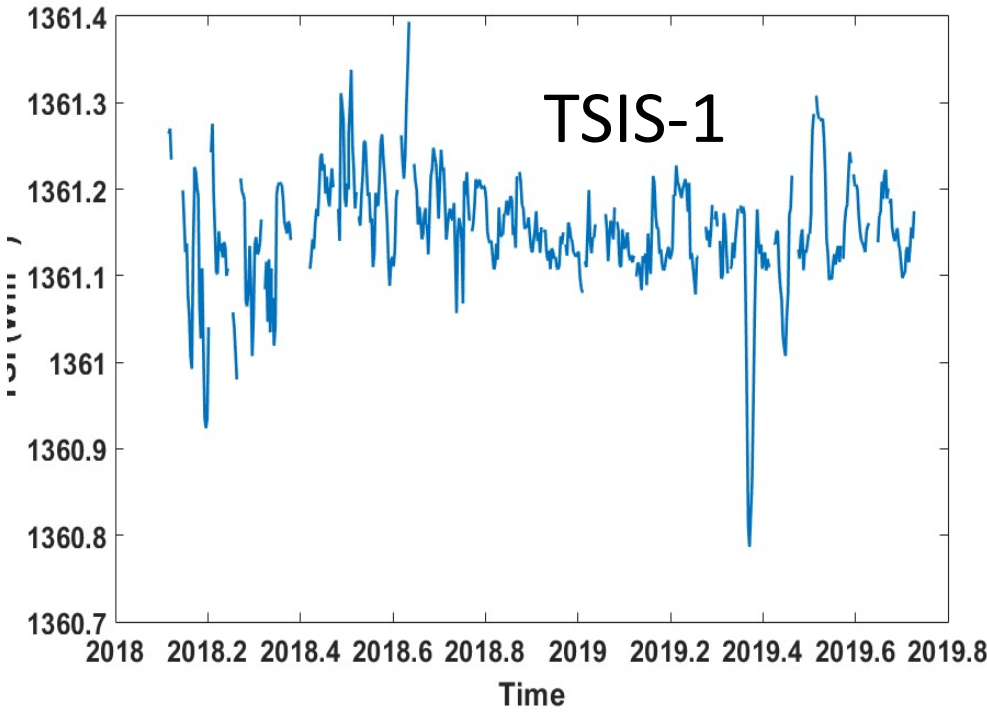

CESM spectral interval: 1, 3, 5, 7, 10, 30, 50 nm
TSIS spectral interval: 0.04~9 nm